

The Radio Spectrum
*Opportunities and Challenges
for the Developing World*

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1. Introduction

The radio spectrum is a major component of the telecommunications infrastructure that underpins the information society. Wireless technologies are used by new entrants to develop own networks and by incumbents to modernize existing infrastructures. Mobile phones are outgrowing fixed service and reach deeply into lower income groups. New fixed wireless technologies in rapid succession result in innovative business models and hold promise to extend competition to all market segments, accelerate development of broadband infrastructures, and connect the rural and urban poor. The spectrum is also widely used for radio and television broadcasting and by the military, and is essential for a broad range of other activities including law enforcement, energy and transportation, manufacturing, medical diagnosis and therapy, global positioning, navigation aids, meteorology, disaster warning, and astronomy, among others.

Spectrum management, however, has not kept up with major changes in technology, business practice, and economic policy during the last two decades. It lags far behind the development of competitive, private-sector led telecommunications reforms worldwide. A vigorous debate is underway on spectrum reforms to overcome persistent shortcomings of the traditional regime. This debate is accelerating and commanding broad public attention.¹ While it is largely taking place in high-income countries such as the U.S. and Europe, its significance is global. Spectrum reform offers low- and middle-income countries important new opportunities as well as challenges. This paper addresses three questions: What is the case for radio spectrum reform? What is the spectrum debate all about? Why does this matter to developing countries? These questions are discussed below. Later work will examine what developing countries can do about these opportunities and challenges and how the World Bank Group could help. The concluding section of this paper proposes some questions that might be addressed at that time.

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2. What is the case for spectrum reform?

Traditional spectrum management practice is predicated on the spectrum being a limited resource that must be apportioned among uses and users by government administration.² The most intensely used part of the spectrum (up to 3 GHz) is allocated among service categories and, within these, assigned to individual users on exclusive or shared bases seeking to prevent interference among them.³ Spectrum management focuses mainly on the rules and procedures for dealing with technical issues, operating and licensing, and administration, with less attention to economics and business practices. Regulations and standards for using the radio spectrum, including worldwide and regional spectrum allocations among some 40 service categories (e.g. mobile, broadcasting, radio astronomy), are negotiated among governments and agreed from time to time at the level of international treaty.⁴ Within this broad framework, spectrum management practices vary among countries (Nunno 2002).

For many years, government administration of the spectrum worked well, and in some situations still does today. These practices, which trace back to the early days of radio telegraphy over 100 years ago, reflected prevailing technology and worked reasonably well under monopoly provision as small numbers of clearly differentiated services evolved at a slow pace. The approach to licensing of most services was essentially first-come, first-served, as there was enough spectrum to accommodate most or all users and permit adequate separation among potentially incompatible uses.

During the last ten years, however, the spectrum has come under pressure from rapid demand growth for wireless services and changing patterns of use. Mobile phone service took off in the mid-1990s, developed at an unprecedented pace, and today has about two billion customers worldwide and is still growing.⁵ Wireless has become the technology of choice to develop existing and new networks by incumbents as well as new entrants in fast-growing competitive telecommunications markets. New wireless devices (e.g. cordless phones, computer routers, Internet hot spots, mobile Internet) have proliferated requiring ever greater spectrum resources. By now the whole spectrum below 275GHz has been allocated at the international level (RA 2002). In many countries the most valuable parts of the spectrum are already allocated to particular services and assigned to

individual users.⁶ This is compounded by technical characteristics of many services that can only be accommodated in certain parts of the spectrum and by long lead times to introduce major new services (OFCOM 2004). Spectrum shortage suppresses competitive entry of new operators and services.⁷ Substantial amounts have been paid for some new wireless licenses.⁸

Spectrum scarcity partly results from the spectrum management regime itself. Spectrum shortages coexist with overall underutilization and inefficient use (Rosston et al. 2001). Frequencies assigned on an exclusive basis are utilized during only a fraction of the time.⁹ Country-wide licenses are often used only in some regions.¹⁰ The authorities cannot readily adjust existing assignments in response to changing demand. Spectrum allocated to new applications that turn out to be unsuccessful remain unused.¹¹ In the absence of appropriate incentives, licensees seldom return unused spectrum or replace old technologies by new solutions requiring less spectrum.¹² The cost of such inefficient use of the spectrum can be huge. By one estimate, about one-half of the total value of the spectrum is wasted on uneconomic uses (The Economist 2004).

Measures have been introduced to mitigate these shortcomings. Some spectrum has been freed to accommodate growth and new services. This has been achieved by reallocating spectrum from one service to another (Cramton et al. 1998), increasing the technical efficiency of spectrum use, increasing the amount of spectrum sharing among services and users, moving towards flexible spectrum allocations,¹³ and extending the upper end of the spectrum.¹⁴ Economic efficiency of spectrum assignment and use has been enhanced through market-oriented measures. Auctions are now commonly utilized when there are more applicants for new licenses than the spectrum can accommodate (e.g. mobile service). Compared with administrative assignment, auctions often are fairer, more transparent, and result in economically more efficient use of the spectrum (Cramton 2001, Lee 2003).¹⁵ Charging for spectrum use to reflect as far as possible its marginal value is expected to encourage efficient use and create incentives to save and return unused spectrum (Cave 2002).¹⁶ Charging government, including the military, for their

spectrum use may potentially release significant portions of spectrum for alternative services.¹⁷

Despite these partial improvements, government administration of the spectrum is now widely regarded as inadequate. It results in major technical and economic inefficiencies, excessive regulatory burden on authorities and companies, limited ability to protect critical uses, and obstacles to technological innovation. Incumbent licensees have minimal incentive to use their spectrum more efficiently, and licenses protect them from competition and innovation (Snider 2003). Market-oriented improvements have yielded limited benefits. Auctions account for only about two percent of all spectrum assignments (The Economist 2004), cannot offset inefficiencies of allocation among services, and arguably can discourage investment (Noam 1998).¹⁸ Administrative pricing of spectrum use is unlikely to accurately second-guess market value. These measures further add to cost and delays, and have lead to several spectacular failures and disputes.¹⁹ Current practices, moreover, do not take full advantage of the possibilities offered by new technologies, and interference management techniques in particular.

Further tinkering with the existing regime at the margin is unlikely to suffice. Improved spectrum management policies and practices are needed to sustain growth, innovation, and efficiency while preserving the balance among broader government goals and capabilities.

3. What is the spectrum debate all about?

In response to the difficulty government administrations have in coping with increasing demands on the spectrum, a growing number of countries are shifting towards alternative models. There are two major trends, one driven by the market, the other by technology innovation (ACA 2000, Lie 2004). Practical solutions are evolving that combine some of the features of both.²⁰

3.1 Market-driven spectrum management: spectrum property rights

Spectrum use can be improved through trading.²¹ Some spectrum rights initially assigned through administrative or market mechanisms to individual licensees for exclusive predetermined uses can subsequently be traded in secondary markets. There is a wide range of options for spectrum trading. Spectrum trading may be restricted to the lease or sale of certain types of whole licenses with no other changes permitted. Or greater freedom may be allowed, such as reconfiguring licenses (sub-dividing and aggregating by geography or frequency), short- or long-term leasing or sharing of some of the license rights, and changing use or technical standards to several degrees (ACA 2002, Cave 2004, Lie 2004). Once a spectrum trading market is in place, markets can be left to develop on their own through private sector mechanisms. Some form of spectrum trading is already in use in a few countries (e.g. New Zealand, Guatemala, United Kingdom, and United States) (NZMED 2000 and 2005, Ibarguen 2003) and is being translated into legislation in the European Union (Analysys et al. 2004).²² Although so far only small parts of the spectrum are being traded, and market intermediation as it exists in other industries has yet to materialize, by some estimates much of the spectrum could be tradable in a few years.²³

The argument for spectrum trading is that it can correct for economic inefficiencies of initial spectrum assignments to users and respond to changing user needs over time. To the extent that the rules allow for changes in use, spectrum trading may also correct some of the artificial scarcities arising from the administrative allocation of spectrum among different classes of uses (van Caspel 2002). Competitive trading allows licensees themselves to evaluate the opportunity cost of spectrum, creates financial incentives to utilize their spectrum efficiently, and may result in unused spectrum being released into the market (Valetti 2001).²⁴ Spectrum trading can lower barriers to entry by reducing the risk of initial investment in licenses as these can be resold, and by allowing new entrants to acquire spectrum in the market rather than lobbying and waiting for new administrative assignments (Cave 2002).

There are concerns, however, that spectrum trading will increase the risk of interference, allow spectrum hoarding by players seeking to restrict competition, lead to high transaction costs in assembling spectrum bands for contiguous geographical areas, and reduce the benefits from international harmonization and standardization (Lie 2004).

Moreover, secondary trading arguably does not go far enough. Licensee rights are generally granted subject to eligibility, service, technical, and implementation requirements. These administrative requirements often result in economic inefficiencies that downstream markets, however well they may work, cannot overcome by themselves.²⁵ Instead, some argue that markets should become the primary means to attribute spectrum among uses and users. To this end, the rights generally granted to licensees should be broadened, permitting flexible use of the allocated spectrum and eliminating all licensing requirements that are not related to interference or anti-competitive concentration (Rosston et al. 2001).

These arguments have led to proposals for developing markets for spectrum property rights akin to those in place for most other industries.²⁶ A licensee would have exclusive and transferable rights to use specified frequencies within a geographic area, with flexible rights of use governed primarily by technical rules to protect against interference. Licensees would be free to sell, lease, divide, and aggregate spectrum parcels without limitation as to uses or technologies other than to comply with interference and competition rules. Other prospective users of these frequencies would need to obtain the licensee's approval and agree on terms and conditions.

The main argument for the spectrum property rights approach is that it would increase dramatically the economic efficiency of spectrum use. One consequence of putting all spectrum on the market would be that so much spectrum might be freed that the price could drop close to zero (Faulhaber et al. 2002).²⁷ Additional arguments include improved transparency (hence reduced opportunity for corruption), faster response to changing technology and demand, and reduced administrative burden on governments and users.

Concerns about the spectrum property rights approach relate mainly to the risk of abuse of market power, government capacity to pursue and preserve social objectives, managing interference and related disputes, and compatibility of technical standards (Valetti 2001). A particular worry is that an all-out property rights regime might encourage commercial hoarding of spectrum rights, which could exclude commercial competitors as well as innovative, non-profit, public-service, or other uses of the spectrum that benefit society as a whole.²⁸ Another concern relates to the transition from the existing system (and existing assignments of rights) to a property rights regime and the initial assignment of rights.

Some, moreover, argue that the move towards markets of spectrum property rights merely entrenches the orthodoxy of licensing the spectrum to singular users,²⁹ while the underlying assumptions of inherent spectrum scarcity and need for exclusive use to protect against interference are being challenged by new technologies.

3.2 Technology innovation-driven spectrum management: spectrum commons

The second major driver of the spectrum debate is technological innovation. Radio technologies now coming to market or under development allow for more efficient use and easier sharing of the spectrum and may render spectrum scarcity obsolete. At the heart of these new technologies is the application of advanced digital processing techniques and resulting increased capability to control interference. Major developments include compression (eliminating redundant information), multiplexing (sharing the capacity of one set of frequencies among several signals), and spread spectrum (distributing one signal over many frequencies) (Snider 2003).³⁰ Other recent innovations include smart radios and antennas, software-defined radios, cognitive radios, and mesh, ad-hoc, or viral networks.³¹ As a group, these technologies enable users not to cause insurmountable interference to each other even when transmitting at the same time, in the same place, and on the same parts of the spectrum.³²

Technological innovation is ushering in a commons approach to spectrum management.³³ In a spectrum commons model, spectrum is available to all users that comply with established technical standards (e.g. power limits) to mitigate potential interference. Usage rights are flexible, with minimal or no restrictions placed on the types of use of the spectrum. In contrast with administration and property rights, both predicated on spectrum scarcity and exclusive use, the commons approach is based on sharing spectrum widely among users without guarantees of interference-free operation. Several specific models are being tried or proposed. The license-exempt model allows using designated bands without a license.³⁴ Sometimes the authorization for use of these bands is accompanied by some limitations, such as regarding transmitted power, range, or protocols.³⁵ A more general open wireless networks model involves qualified users managing themselves the use of spectrum as public property through intelligent use of technology (Benkler 1998).³⁶

Different forms of spectrum commons are already in place in several countries, usually in the bands allocated to industrial, scientific and medical devices.³⁷ The advent of technologies such as WiFi, and more recently WiMax, open up opportunities for broadband access in license-exempt bands, at various distance ranges. According to the ITU, by late 2004, 55 countries had allocated spectrum for license-exempt use (ITU 2004). There are numerous consultations underway around the world about extending the commons approach to additional services. The trend is for license-exempt use to grow. Several countries have also permitted the use of some new technologies, such as ultra-wide band (UWB), to operate across bands in which exclusive user licenses are in use, acknowledging that spectrum sharing is possible. The U.S. is also furthering this idea by discussing the concept of allowing any transmission whose interference does not surpass a certain level to exploit already-assigned frequencies (FCC 2003a).³⁸ These initiatives, however, stay shy of the more general idea of open wireless networks.

The argument for a spectrum commons is mainly that it encourages spectrum-efficient new radio technologies.³⁹ A spectrum commons also precludes spectrum warehousing, can reduce spectrum scarcity,⁴⁰ and may result in lower capital requirements.⁴¹ By

promoting technological innovation, the commons approach lowers entry barriers and enhances competition. The regulatory and financial burden on all players is reduced, as users do not need to obtain exclusive licenses since the new technologies themselves provide more cost-effective alternative means to contain interference. Moreover, exclusive-use licensing is poorly suited to authorize these new technologies, and thereby delays the benefits they can bring (Ikeda 2003, Benkler 2002, Reed 2005).

The main concern about the commons approach is that, to the extent that spectrum scarcities may remain despite technological innovation, there is the risk that the commons will be overused and result in excessive interference.⁴² Associated risks are spectrum hoarding and intentional harmful interference.⁴³ Related areas of concern include enforcement,⁴⁴ managing spectrum disputes,⁴⁵ coexistence with legacy equipment,⁴⁶ and irreversibility of deregulation and related loss of government control of the spectrum.⁴⁷ Moreover, there are some indications that a commons regime may not be as attractive to investors as an exclusive rights system (FCC 2003).⁴⁸

3.3 Combined approaches: administration, property rights, commons

Looking forward, at least in the medium term, the debate on spectrum reform is not ushering in immediate wholesale replacement of current policies and practices. Rather, the balance between administration, property rights, and commons is shifting. Although either the spectrum rights or the commons approach to the spectrum arguably would be an improvement over traditional administration, it is unclear whether and which one would be best in the long run.

Comparisons among spectrum management models depend on complex tradeoffs among factors and on how the different models are defined (Ting et al. 2004). The spectrum rights approach is likely to work best where there is acute spectrum scarcity and the transaction costs of moving spectrum from low to high value uses is low. When transaction costs are high, the rights model would arguably still be better than administration but some economically efficient adjustments would not take place (FCC 2002). In the medium term, exclusive spectrum rights (either under government

administration or a property rights regime) might be appropriate where large-scale investments in network infrastructure are needed. Commons approaches have advantages for short range communication, in relatively closed spaces (such as offices, hotels, or airports), or where communication density and use of the spectrum are low such as in rural areas.

The different models are not necessarily mutually exclusive.⁴⁹ Commons can work alongside a property rights solution while reducing transaction costs. A group of frequencies could be organized as a commons among participants but have exclusive rights with respect to third parties. Mobile operators own the right to use certain frequency bands, but their customers share these bands regulated through technology.⁵⁰ Equipment suppliers could acquire exclusive spectrum rights within which the buyers of their products would operate on a shared basis. Amateur radio is a service where many individually licensed users share parts of the spectrum in common.⁵¹

Spectrum rights can be designed so as to approximate some of the benefits of the commons model. A variant of the exclusive property rights approach would subject licensees to government-mandated easements. Easements would, for example, allow other users to transmit on the same frequencies without the licensees' authorization, provided they do not interfere with the licensees' services (Faulhaber et al. 2002).⁵² This variant addresses the high transaction costs that otherwise would be incurred by users of several new technologies now coming to market (e.g. ultra wide band, software-defined radios) that have considerable spectrum-saving potential and network development advantages but need broad access to the spectrum.⁵³ Easements could also address high transaction costs for users that need immediate but short-term access to certain portions of the spectrum (e.g. public safety agencies) or global access to spectrum under harmonized rules (e.g. satellite operators) (FCC 2002).⁵⁴

Ways have been outlined to make a rapid transition between approaches, for example from administration to property rights (Kwerel 2002).⁵⁵ In most countries, however, the regime is likely to be adjusted only gradually. It may be necessary and possible to

experiment with property rights and commons in a scale large enough to achieve effective results, yet retain the option of later choosing one or the other solution (Benkler 2002).

In most realistic scenarios for migrating from spectrum administration to property rights or commons approaches, administration will continue to play a significant, if declining, role.⁵⁶ This recognizes the existence of large vested interests and sunken costs associated with the outcomes of each approach. Also, some government intervention and regulation will be unavoidable to reconcile diverse public policy objectives, deal with market imperfections and with harmful interference when it occurs, and ensure that international obligations are respected. In particular, each country's ability to contain anti-competitive behavior, including strategic behavior of firms in spectrum markets, will condition the pace at which spectrum management can be overhauled. Improvements are possible in current spectrum administration practice. For example, where the major demand for a particular service is limited to areas of high population density, other services could use the same frequencies outside these areas. Frequencies used by military installations in remote parts of the country can be shared by civilian applications elsewhere (RA 2002). Most developing countries have considerable potential for bringing spectrum administration up to current best practice.⁵⁷

Changes in spectrum management at the national level will be conditioned by related progress at the international level. Given the propagation characteristics of radio signals, there needs to be some degree of coordination, if not of harmonization, of the different spectrum arrangements in order to avoid interference. Also, in the interest of consumers, it is desirable to maintain some level of international uniformity to support economies of scale in device production and global circulation, such as in roaming. In debating the direction and pace of change of national spectrum management, governments would do well to also reflect on how to best use regional frameworks for coordination, harmonization, and debate at the international level.⁵⁸

4. Why does all this matter to developing countries?

This debate on spectrum management reform is deeply relevant to developing countries. It could be argued that the debate arises out of the circumstances that prevail in high-income countries: acute scarcity of spectrum coexisting with widespread underutilization, intense pressure of a large manufacturing sector to develop markets for new technologies, a dynamic private sector interested in developing new business opportunities and capable of mobilizing the necessary skills and financial resources, and mature institutions capable of dealing with complex issues and enforcing sectoral and general competition laws and rules. These are not the typical conditions prevailing in low- and middle-income countries. Yet the significance of the changes underway is global. Below are some reasons why this is the case in developing countries.

- Spectrum management typically lags way behind sector reforms leading to competitive, private led telecommunications markets. This poses growing obstacles to further sector development. Improving spectrum administration would yield significant benefits, but governments may wish to consider moving straight into property rights or commons approaches. Developing countries at an early stage of building up spectrum management capacity may benefit from adopting new solutions from the start.⁵⁹ These may be especially well suited for low- and middle-income countries.⁶⁰
- Wireless has become the technology of choice for developing existing and new networks. Developing countries have the opportunity to import new technologies at marginal cost. In turn, they add scale to global production further reducing costs and accelerating innovation.⁶¹ Developing countries also can become fertile testing grounds in the early stages of commercial deployment. Thus, although emerging economies (not even the largest ones, such as China or India) are not yet in a position to take technological leads that diverge from major industrial markets, they play an active role in technological innovation.⁶²

- Governments seeking to benefit from the new technologies must remove impediments to their adoption. This requires being aware of the new opportunities and challenges, identifying aspects of the legal and regulatory framework that pose obstacles to early adoption, and strengthening capacity to implement modern solutions in a fast-changing global environment.
- New spectrum solutions cannot be adopted without careful examination of their relative merits in specific contexts. Not all developing countries would do well by replicating best practices from high-income countries. While the broad drivers and principles of change are likely to be similar across a wide range of countries, the specific solutions may need to be designed with an open mind, and the path of change calibrated case by case.
- Developing countries can add global momentum to spectrum reform. Solutions that prove themselves in a few high-income countries may catch the attention of innovators in some developing countries. Initial successes could diffuse quickly throughout the developing world, as has occurred with telecommunications sector reforms.⁶³
- Developing countries play a significant role in international governance of the spectrum. Most countries are active members of the ITU. A growing number subscribe to trade agreements that deal with telecommunications. It is to their advantage to participate effectively in the process of changing the global and regional frameworks for spectrum management, but shortage of funding is a pervasive constraint.

5. Conclusion

The debate underway on alternatives to traditional government administration of the spectrum is relevant to all countries. Although the debate is mainly taking place in high-income countries, it can usefully inform policy decisions in a much wider range of economies. A systematic assessment of the relative merits of each approach under given

country conditions remains to be undertaken, and solutions will vary among countries, but some broadly relevant questions can already be raised:

- How would the various approaches to spectrum management fare in low-income countries? These countries often have weak governance, incomplete infrastructure networks, large rural populations with minimal service, fast growth, and persistence of legacy equipment.⁶⁴ Given that in the past many have had difficulty establishing and enforcing sector rules, can they be expected to perform better under alternative spectrum models? Would they have sufficient institutional capacity and expertise to undertake regime changes?⁶⁵
- How much effort should be invested in improving government administration of the spectrum? There is ample opportunity to improve existing arrangements, but how far should the governments go building up a system that is expected to have a declining role? What would happen if developing countries maintained their current spectrum policies? What should prompt them to change, and when? Rather than move to a different model, would some developing countries not be better off by cleaning up, assigning, and more effectively policing spectrum use under better government administration?
- What agencies could deal with harmful interference and resolve disputes? In the context of weak sector regulation and often non-existing competition law and enforcement, can this function be outsourced? A commons approach presumes some self-regulation among users. Can this be expected in emerging markets?
- Are market approaches to spectrum management sufficiently participatory, or is there a danger that spectrum will be cornered by a few influential players? How can strategic behavior of incumbents be contained? How much spectrum should governments place on the market?

- Who would pay for the cost of spectrum regulation as larger segments are released for unlicensed use? How can government treasuries be weaned from the large rents they have grown accustomed to exact from spectrum licensees?
- How can spectrum policies be better integrated with telecommunications and broadcasting sector reforms and economic policy generally? How can the interests of diverse stakeholders be reconciled? What are viable institutional solutions to achieve this? How serious is the problem of spectrum assigned to the military and security forces?

References

- Analysys and DotEcon. 2004. 'Study on conditions and options in introducing secondary trading of radio spectrum in the European Community.' Accessible at http://www.dotecon.com/images/reports/secontrad_final.pdf.
- ACA. 2002. 'Inquiry Report - Review of Radiocommunication Acts and of the Market Based Reforms and Activities Undertaken by the Australian Communications Authority.' Australian Communications Authority, Report No 22, 1st July 2002. Accessible at <http://www.pc.gov.au/inquiry/radiocomms/finalreport/radiocomms.pdf>.
- Bauer, J. 2002. 'A Comparative Analysis of Spectrum Management Regimes.' Telecommunications Policy Research Conference, Arlington, Virginia. Accessible at <http://intel.si.umich.edu/tprc/papers/2002/85/SpectrumManagement.pdf>.
- Bauer, J. 2003. 'Impact of license fees on the prices of mobile voice service.' *Telecommunications Policy* 27 no. 5-6, pp. 417-434.
- Benkler, Y. 1998. 'Overcoming Agoraphobia: Building the Commons of the Digitally Networked Environment.' *Harvard Journal of Law & Technology* vol.11 No. 287. Accessible at <http://www.benkler.org/agoraphobia.pdf>.
- Benkler, Y. 2002. 'Some Economics of Wireless Communications.' *Harvard Journal of Law and Technology*, Volume 16, No 1. Accessible at <http://jolt.law.harvard.edu/articles/pdf/v16/16HarvJLTech025.pdf>.
- Carter, R., A. Lahjouji, and N. McNeil. 2003. 'Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues.' Federal Communications Commission Working Paper #39, May 2003. Accessible at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-234741A1.pdf.
- Cave, M. 2002. 'Radio spectrum management review; an independent review for the DTI and HM treasury.' Accessible at http://www.Ofcom.org.uk/static/archive/ra/spectrum-review/2002review/1_whole_job.pdf.
- Faulhaber, G. and D. Farber. 2002. 'Spectrum Policy Task Force Report.' Federal Communications Commission, Washington, DC. Accessible at Spectrum Management: Property Rights, Markets, and the Commons", AEI-Brookings Joint Center, Working Paper 02-12. Accessible at <http://www.aei-brookings.org/admin/authorpdfs/page.php?id=217>.
- FCC. 2002. 'Report of the Spectrum Rights and Responsibilities Working Group.' Federal Communications Commission Spectrum Policy Task Force, November 15, 2002. Accessible at <http://www.fcc.gov/sptf/files/SRRWGFinalReport.doc>.
- FCC. 2003a. 'Notice of Enquiry and Notice of Proposed Rulemaking – Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed operation in Certain Fixed, Mobile and Satellite Frequency Bands.' Federal Communications Commission, ET Docket No. 03-237. Accessible at http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-289A1.pdf.

- FCC. 2003b. 'Allocations and Service Rules for the 71-76 GHz, 81-86 GHz and 92-95 GHz Bands.' Federal Communications Commission. Accessible at <http://wireless.fcc.gov/services/millimeterwave>.
- Gast, M. 2002. *802.11 Wireless Networks – The Definitive Guide*. O'Reilly, Sebastopol CA.
- Hatfield, D. 2005. 'Spectrum Management Reform and the Notion of the Spectrum Commons.' *Southern African Journal of Information and Communication*, No. 4, Spring 2005. Available at <http://link.wits.ac.za/journal/j0401-hatfield-spectrum.pdf>.
- Hazlett, T. 1998. 'Assigning Property Rights to Radio Spectrum Users: Why Did FCC License Auctions Take 67 Years.' *The Journal of Law and Economics*, Volume 41, Number 2, Part 2. Accessible at <http://www.manhattan-institute.org/hazlett/rahazl3.pdf>.
- Ibarguen, G. 2003. 'Liberating the Radio Spectrum in Guatemala.' *Telecommunications Policy*, Volume 27, Issue 7, pp.543-554.
- Ikeda, N. 2003. 'Spectrum Buyouts: A Mechanism to Open Spectrum.' Revised December 2003, Research Institute of Economy, Trade, and Industry, Tokyo. Accessible at <http://www.rieti.go.jp/jp/publications/dp/02e002.pdf>.
- ITU. 2004. *Trends in Telecommunication Reform 2004/2005: Licensing in an Era of Convergence*. International Telecommunication Union, Geneva.
- Jain, R. 2001. 'Spectrum Auctions in India: Lessons from Experience.' *Telecommunications Policy*, Volume 25 (10/11) pp 671-688.
- Klemperer, P. 2002. 'How (Not) to Run Auctions: the European 3G Telecom Auctions.' *European Economic Review*, Volume 46, pp 829-45. Accessible at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=297907.
- Kurtin, O. 2003. 'NextWave Supreme Court Victory Ends Five-Year Struggle over US Wireless Auction Rules.' *Telecomfinance* 99. Accessible at <http://www.salans.com/publications/pdf/pub1058lang1.pdf>.
- Kwerel, E. 2000. 'Spectrum Auctions Do Not Raise the Price of Wireless Services: Theory and Evidence.' Federal Communications Commission White Paper. Accessible at <http://wireless.fcc.gov/auctions/data/papersAndStudies/SpectrumAuctionsDoNotRaisePrices.pdf>.
- Kwerel, E. and J. Williams. 2002. 'A proposal for a rapid transition to market allocation of spectrum.' Federal Communications Commission, OPP Working Paper No. 38. Accessible at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-228552A1.pdf.
- Neto, I. 2004. 'Wireless networks for the developing world: the regulation and use of license-exempt bands in Africa.' MIT, Cambridge, MA.
- Noam, E. 1998. 'Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Taking the Next Step to Open Spectrum Access.' *Journal of Law & Economics*, Volume 41, Issue 2, pp 765-790. Accessible at <http://www.citi.columbia.edu/elinoam/articles/SPECTRM1.htm>.

- Nunno, R. 2002. 'Review of spectrum management practices.' International Bureau, Strategic Analysis and Negotiations Division, Federal Communications Commission. Accessible at http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-229047A1.pdf.
- NZMED. 2000. 'New Zealand Spectrum Management, a decade in review: 1989 – 1999.' New Zealand Ministry of Economic Development, Wellington. Accessible at <http://www.med.govt.nz/rsm/publications/pibs/pib35.pdf>.
- NZMED. 2005. 'Review of Radio Spectrum Policy in New Zealand.' New Zealand Ministry of Economic Development, Wellington. Accessible at <http://www.med.govt.nz/rsm/spp/review/report/report.pdf>.
- Ofcom. 2004. 'Spectrum Framework review.' Office of Communications U.K., November 2004. Accessible at <http://www.g3psm.net/sfr1.pdf>.
- RA. 2002. 'Strategy for the future use of the Radio Spectrum in the U.K.' Radiocommunications Agency, April 2002.
- Reed, D. 2001 'Why spectrum is not property - the case for an entirely new regime of wireless communications policy.' Accessible at <http://www.reed.com/dprframeweb/dprframe.asp?section=paper&fn=openspec.html>.
- Rosston, G. and T. Hazlett. 2001. 'Comments of 37 Concerned Economists.' In the Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, Federal Communications Commission. Accessible at <http://www.aei-brookings.org/admin/authorpdfs/page.php?id=417>.
- Snider, J. 2003. 'An Explanation of The Citizen's Guide to the Airwaves.' New America Foundation, Washington DC. Accessible at http://www.newamerica.net/templates/ssl_forms/download/airwaves.pdf.
- Staple, G. and K. Werbach. 2003. 'The Coming Spectrum Explosion— A Regulatory and Business Primer.' *Communications Lawyer*, Volume 21, No.3. Accessible at New Zealand Ministry of Economic Development, <http://werbach.com/docs/Staple&Werbach.reprint.pdf>.
- The Economist. 2004. 'On the same wavelength.' *The Economist*, Special Report Spectrum Policy, August 14-20, pp 61-63.
- Ting, C., S. Wildman, and J. Bauer. 2004. 'Modeling the Efficiency Properties of Spectrum Management Regimes.' Working paper, Department of Telecommunication, Information Studies, and Media, Michigan State University, Telecommunications Research Project, Lansing, MI. Accessible at <http://quello.msu.edu/wp/wp-04-03.pdf>.
- TRP. 2003. *Tutorial on Spectrum Management*. Section 2, Telecommunications Research Project, Hong Kong. Accessible online at http://www.trp.hku.hk/e_learning/spectrum/section2.html.
- Valetti, T. 2001. 'Spectrum Trading.' *Telecommunications Policy* Volume 25: pp 655-657
- Werbach, K. 2004. 'Supercommons: Toward a Unified Theory of Wireless Communication.' *Texas Law Review* Vol. 82:863-973. Accessible at <http://werbach.com/research/supercommons.pdf>.

Notes

¹ For example, a workshop on spectrum management was held by the International Telecommunication Union (ITU) in February 2004. The first progress report on implementing new spectrum policies in the European Communities was issued in July 2004. The Economist published in August 2004 an extensive article on spectrum policy. Spectrum reform topics figured prominently in the Telecommunications Policy Research Conference in October 2004 and again in 2005. Spectrum trading has or is being introduced in New Zealand, the United Kingdom, and other OECD countries. Commercial trials of broadband wireless service are underway in Peru and some other developing countries using license-exempt spectrum made available by the authorities.

² Government administration of the spectrum is sometimes referred to as 'command and control' spectrum management.

³ Below 3 GHz, approximately 25% is reserved for exclusive government use, 35% for exclusive private use, and 40% for shared uses. For the entire range of usable spectrum, shared use is dominant, with more than 90% of spectrum between 0-300 GHz allocated to shared uses.

⁴ The ITU provides the framework for radio spectrum management worldwide, specifies the technical characteristics and operational procedures for wireless services, and coordinates the use of satellites for communication, broadcasting, and meteorology. This is done primarily through the World Radio Conference, which is convened by the ITU every three or four years.

⁵ This is double the number of fixed phone lines. Mobile phones took less than a decade to catch up with a century of fixed telephone service development.

⁶ Different propagation characteristics make some frequencies more desirable than others for particular applications. According to one estimate, the one percent of frequencies that are below 3GHz are worth more than the 99 percent from 3GHz to 300GHz (Snider 2003). The most valuable frequencies are sometimes referred to as 'beach-front' spectrum.

⁷ This is in addition to the deliberate restriction of the number of spectrum licenses as a means to contain competitive pressure on incumbent operators or exact high license fees as windfall government revenues, both common practices in developing countries.

⁸ For example, for third generation broadband mobile licenses in Germany and the UK. Overvalued stock markets and aspects of auction design also may have contributed to high bid prices.

⁹ By one estimate, only five percent of the U.S. government's spectrum is used in any particular instant (The Economist 2004).

¹⁰ Broadcast television channel 3 is vacant in New York because it is occupied in Philadelphia. This type of channel allocation plan was arguably necessary for interference-free reception of high-powered local stations in the 1950s, but technology has now moved on (Staple et al. 2003).

¹¹ Examples are the Terrestrial Flight Telephone System (TFTS), the European Radio Messaging System (ERMES), and to some degree the digital Terrestrial Trunked Radio (TETRA) (OFCOM 2004).

¹² Examples are some old radars still in operation, and the case of UHF broadcast television. Satellite television could provide the same local channels as today's digital broadcast television, while also freeing up the broadcasters' valuable spectrum. The spectrum administration regime does not assign value to spectrum as a tradable asset. Some suggest adopting 'use it or lose it' rules (Cave 2002).

¹³ In some cases, a broad range of uses is allowed (e.g., mobile voice and data), reducing somewhat the problems from rigid allocations that were typical in the past.

¹⁴ This is well illustrated by the upper limits of the ITU's frequency tables which stood at 200MHz before 1947, and in 2003 were up to 275 GHz (TRP 2003).

¹⁵ Traditional administrative assignment practices include first-come-first-served, lotteries, and comparative hearings ('beauty contests').

¹⁶ In the UK it was recommended to increase spectrum prices to full levels derived from an opportunity cost approach (even where licenses were not subject to auction), and refocus definition of congested areas so that spectrum pricing would align incentives for efficient spectrum use (Cave 2002). Australia also charges its military for frequency use and is moving toward a scheme in which the defense authorities must obtain licenses for their systems.

¹⁷ Managing military spectrum efficiently is particularly important. In many countries, including the USA and the UK, the military are the largest single user of spectrum. In the UK, they are allocated nearly 50 per cent of bands in the range 3-10 GHz as well as extensive frequencies in other ranges (Cave 2002). In the

US, 64 percent of the spectrum under 3.1GHz is allocated to either exclusive or shared federal (including military) use (Snider 2003). In countries formerly part of the USSR the proportion of spectrum controlled by the military is often even higher, possibly over 70 percent. Yet typically there is little accountability for efficient use of this spectrum, partly justified by political and strategic reasons. There have been cases of reallocation of military spectrum to civilian use. In the UK, for example, the spectrum for first-generation mobile telephony was released for civil use by the Ministry of Defence. It is generally believed, however, that the right mechanisms and incentives are not yet in place. In the UK, since 1999 the Ministry of Defence has faced spectrum use prices comparable to those levied on civil use. As of 2002 it was paying around £23m per year for most of its mobile radio and fixed links bands (Cave 2002).

¹⁸ Whether auctions also contribute to higher prices is a question under debate. Evidence from the U.S., suggests that the use of auctions does not result in higher service prices but rather in lower profits (Kwerel 2000, Bauer 2003).

¹⁹ The attribution of 3G licenses in Europe around 2000 illustrates the dangers of overbidding and the financial burden this places on operators (Klemperer, 2002). In the US, auctions in 1996 of PCS spectrum blocks reserved for small businesses and other designated entities (C and F blocks) led to some firms being unable to meet license payment obligations, bankruptcy, threat of revoking licenses, and protracted litigation all the way up to a Supreme Court decision in 2003 (Kurtin 2003). After the issuance of wireless licenses tendered in India in 1995, operators realized they could not honor their obligations, and following negotiation the government had little choice but to change the financial terms. A long process followed where the government and operators argued over their understanding of specific clauses. Eventually the case went up to the telecommunications disputes settlement and appellate tribunal, consuming considerable time and resources. For more details on the case of India see

<http://tdsat.nic.in/Petition%20No.10%20of%202001.htm>

²⁰ Market and technology also were the two main drivers of telecommunications reforms from the 1980s. But whereas these twin and interdependent drivers led to a common set of reform propositions, in the current spectrum debate they result in sharply differentiated property rights and commons solutions. These, however, may be converging.

²¹ Some spectrum has always been traded, albeit in contorted ways. A prime example is the sale of radio and television broadcasting stations. The huge prices paid for these stations reflect the value of the frequencies, not the equipment or even the client base.

²² See also Bauer 2002, Hazlett 1998, and Kwerel et al. 2002.

²³ In 2010 more than 70 percent of the UK spectrum is likely to be tradable (Ofcom 2004).

²⁴ Spectrum trading enabled the creation of a fourth broadcasting network in New Zealand covering 70 percent of the population and is credited with an increase in telephone penetration in Guatemala.

²⁵ Eligibility requirements (e.g. reserving spectrum bands for small enterprises) can impose costs on consumers by giving priority to relatively inefficient suppliers or encouraging market distortions to fit the rules. Service requirements that mandate some services and prohibit others (e.g. excluding PCS licensees from offering fixed services or broadcasting) may prevent spectrum from being used to deliver the services that the public most wants to receive. Technical restrictions (e.g. specifying the technology to be used to deliver a specific service) may discourage innovation. Implementation requirements (e.g. roll-out schedules) impose constraints that may be inconsistent with the licensees' business plans.

²⁶ The spectrum property rights approach is also referred to as the market approach. Although the case for market approaches to spectrum management was persuasively made in the 1950s, it only started to develop as a mainstream current of change around 2000. For a discussion of the '...political stability of economically inefficient licensing methods...' in the US, see Hazlett 1998.

²⁷ Spectrum for government use, including military, would be subject to the same treatment. The argument is that they should pay for spectrum use as they do for all other inputs.

²⁸ Safeguarding fair competition requires effective regulatory oversight, in terms of either general competition law or sectoral regulation. This should work for spectrum management as well. As for social objectives, the trend is to handle them separately from commercial supply of services and networks, such as through explicit cash subsidies for universal service rather than in-kind contributions of spectrum and other inputs.

²⁹ Conceding spectrum rights in perpetuity also raises concerns about the government losing control of a public asset. Guatemala has been very innovative with respect to spectrum management, and has been an

early adopter of spectrum trading. Having given away all spectrum rights (Ibarguen 2003), it is now facing difficulties when wanting to recover some bands for license-exempt use.

³⁰ For example, 50 years ago, a single conversation could require a dedicated 240 kHz channel. With compression and multiplexing, today around 100,000 telephone calls can be handled in the same spectrum previously designated to handle only one call. Similarly, in 1960 a 6 MHz channel could only carry one standard definition analog TV channel, whereas today it can carry ten such channels (Snider 2003). Compression and multiplexing were conceived over 50 years ago, mainly for use over wires and cables, but developed to their current level with the introduction and sustained progress of advanced semiconductors (integrated circuits) and computers. Examples of technologies using spread spectrum techniques are WiFi, which allows large numbers of users to share radio frequencies, and Ultra-Wide Band (UWB) radios, which can transmit high-speed data over a wide range of frequencies using very low power.

³¹ Smart radios add context-sensitive intelligence to signal processing, so receivers can distinguish among different signals sharing the same frequencies. This is similar to human hearing discriminating between noise and signal to focus on a particular conversation with others going on around. Smart antennas can discriminate among signals coming from different directions. Software-defined radios can switch operating frequencies dynamically in response to spectrum congestion and noise. Cognitive radios sense and respond to their environment by choosing communications characteristics that are compatible with it (Bauer 2003). Mesh, ad-hoc and viral networks are all related concepts applying to network topology, and gravitate around the notion of incremental or decentralized networks, needing no central backbone, infrastructure, or organization in order to work, but scaling up by using ‘neighbors’ as resources for communication (Neto 2004). Wireless mesh networks are multi-hop systems in which end-user devices assist each other in transmitting data through the network, especially in adverse conditions.

³² Although these technologies are currently being developed and will take some time to become widely deployed, they may eventually reduce spectrum scarcity dramatically.

³³ We use ‘commons’ as a generic term that also includes what various authors refer to as unlicensed approaches, spectrum deregulation, or open wireless networks. They are all based on sharing spectrum rather than attributing it to individual uses and users.

³⁴ Deregulating spectrum access by promoting license exemption (for example for the use of WLAN technologies) can offer significant advantages for users, in particular the cost savings and convenience resulting from the possibility of using radio equipment without the need to apply for a license. It also benefits innovation, as it gives entrepreneurs the grounds to experiment with new technologies or business models (Neto 2004).

³⁵ It is important to recognize that unlicensed does not mean unregulated. See, for example, ITU-R Resolution 229, adopted at the World Radio Conference in 2003 (WRC-03), on the “Use of the bands 5150-5 250MHz, 5250-5350MHz and 5470-5725MHz by the mobile service for the implementation of wireless access systems including radio local area networks.” This resolution created the first globally-harmonized bands for unlicensed WLANs as a primary allocation. But to protect existing co-primary users in these bands, including radar systems, WLANs are required to have interference-mitigation capabilities and built-in protocols.

³⁶ Benkler (1998) argues that this means regulating wireless communications as the Internet, with minimal standard protocols and limited governmentally-imposed rules of the road. In the Internet domain, a decentralized commons structure is possible because the network’s intelligence lies in the decentralized nodes, i.e. the computers (Hatfield 2005). In the spectrum domain the nodes would be the radio receivers - hence the potential for smart and cognizant radios. It can be argued, however, that in the Internet domain management models started with the commons approach, but that there is now the need to introduce some intellectual property and administrative (ICANN) governance functions. The challenge faced in Internet governance, as in the spectrum domain, is to find the right balance between the different models.

³⁷ The Consumer Electronics Association in the U.S. estimates that there are around 350 million license-exempt devices in use in applications such as cordless telephones, garage door openers, remote-control toys, baby monitors, home security systems, and automobile keyless entry systems (Hatfield 2005).

³⁸ This concept is referred to as ‘interference temperature’.

³⁹ Because under the commons approach no spectrum is exclusively held, users have incentives to create spectrum-efficient technologies that use whatever spectrum is available, whereas exclusively licensed spectrum typically sits idle when the license-holder is not transmitting (FCC 2002). Commons may also

encourage a kind of technological evolution, in which devices that better tolerate interference will win more buyers and gradually displace less resilient equipment from the market. New wireless systems also may be the technology of choice in parts of developing countries where the spectrum is not very congested. This results from lower initial capital costs than conventional systems and ease of deployment and relocation.

⁴⁰ Because of the efficiency gains expected of the new technologies and the different spectrum demands of new architectures (e.g. mesh networks).

⁴¹ Capital costs can be distributed among users (e.g. through mesh networks) rather than being concentrated in traditional supply infrastructures.

⁴² Despite technology evolution, there is a limit to the number of devices that can coexist. Some technical parameters may be needed to keep interference at manageable levels in high-occupancy areas. Even so, if spectrum shortages remain, the spectrum could have too many users and overall performance decline. As earlier with fishing in international waters, overgrazing of public pastures, and other situations, this has been labeled 'the tragedy of the commons'.

⁴³ We can draw a parallel between these and Internet spam.

⁴⁴ Some level of regulatory enforcement may be needed to prevent excessive interference and free rider problems (Hatfield 2005).

⁴⁵ Deregulated spectrum is generally seen as being of an unprotected nature. Who should be responsible for resolving disputes on interference?

⁴⁶ Whereas new devices may behave nicely in a coexistence scenario, traditional technology may not, and there may be situations where these coexist in the same or adjacent frequency bands. Short-range low power devices for mass market applications invariably have limited receiver performance in terms of poor selectivity, rendering them liable to interference from generally higher power older devices operating in adjacent licensed bands.

⁴⁷ From a spectrum management point of view, the process of deregulating a band would be very difficult to reverse, as there will be no record of the equipment in use and no way of requiring its use to be discontinued other than the slow process of waiting for the items in use to reach the end of their life (RA 2002).

⁴⁸ Firms that require large fixed investments might have trouble attracting capital because of the lack of assurances against future interference.

⁴⁹ Comparing spectrum with land, even in countries with strong market-oriented economic systems, privately owned property and property shared in common (e.g. land set aside for parks or highways) coexist side by side (Hatfield (2005).

⁵⁰ In the GSM system, for example, users are able to share spectrum by assigning different slots to users, but also by using spread spectrum techniques.

⁵¹ Amateur radio is a hobby enjoyed by about three million people worldwide. They use internationally allocated bands to experiment and communicate using voice, data, or video technologies. Amateur radio operators are licensed and given unique identification call signs by their governments upon passing tests on related technical and regulatory subjects. Amateur radio operation is subject to regulations in each country. Enforcement of regulations and management of interference are largely achieved through voluntary adherence to codes of behavior.

⁵² The FCC recently published two decisions which give interference rights to unlicensed users and non-exclusive use rights to licensed users in different bands (FCC 2003b).

⁵³ Examples are technologies that require simultaneous low-power use of a wide spectrum range (e.g. ultra-wide band technologies) and short term access to individual frequencies over a wide spectrum (e.g. software-defined radios).

⁵⁴ Engineers are concerned that there are more serious limits for radio devices to recognizing the radio environment in which they operate (which would be a precondition to design an underlay approach). Ways out may include requiring existing users to broadcast characteristic signatures that would make it easier to detect their presence. More thinking in this area needs to be done and it will likely not be sufficient to just declare that devices may use any frequency as long as they do not interfere.

⁵⁵ The transition from spectrum administration to property rights in the US could use a two-sided auction in which the FCC would offer unassigned spectrum in a band simultaneously with encumbered spectrum offered by existing licensees. Limited initial application of this approach could make available over 400 MHz of highly valuable spectrum for new uses in 2-5 years. If results are satisfactory, the approach could

be extended across much of the spectrum to bring about a permanent solution (Kwerel et al. 2002). Jim Snider at the New America Foundation has argued, however, that such an approach would create a windfall of \$780 billion for the broadcasting industry.

⁵⁶ Advantages include the clear roles and responsibility for managing spectrum and interference.

⁵⁷ A project by *infoDev* and the ITU to develop an online telecommunications regulation handbook includes a module on spectrum management. See

http://www.infodev.org/section/programs/enabling_access/telecom_toolkit

⁵⁸ There may be a political and geographical dimension to the selection of spectrum management model. The choice between, say, the administration and property rights approaches, may be related to the political regime and industrial policy in place in the country. The models in Africa, for example, may well be influenced by the choices made in Europe, given the close economic relationships between both continents.

⁵⁹ This bears some resemblance to the early adoption by Latin American countries of the new trends away from state monopolies towards private-led, competitive markets in the mid-1980s, on which they were able to move along faster than in most of the developed countries where the trends originated.

⁶⁰ For example, developing countries often have large rural populations widely dispersed across areas with little spectrum use or risk of interference. A commons model could be well suited in these areas, whereas congestion in the main urban areas may point towards a property rights approach. The institutional capacities are often quite limited, however, so solutions that are intensive in regulatory control may not be feasible in the short term.

⁶¹ For example, the bulk of current growth of mobile phone network and customer equipment is now in developing countries.

⁶² It could also be argued that as a consequence of changes in spectrum policy, radio equipment in the developed world would become obsolete, and could be bought in the developing world at less than the marginal cost of new equipment. Similar situations arose in the past, for example when electromechanical switches were replaced by electronic switches and offered at low prices to developing countries. Past experience, however, suggests that obsolescent technologies are uneconomical in developing and much as developed countries.

⁶³ This happened with telecommunications competition and privatization following the pioneering reforms in a few Latin American countries in the late 1980s. More recently, Morocco played a similar lead role in the late 1990s catalyzing change in other Northern African countries.

⁶⁴ Enabling decentralized bottom-up solutions can be more appropriate to the political reality of developing countries: in the context of numerous institutional and structural obstacles to entry, license-exempt regulation potentially provides a friendly environment for entrepreneurship, reducing barriers to entry and the risk of regulatory capture (Neto 2004). It has also been argued that lower risk of interference (e.g. in rural areas) may warrant easier access to spectrum, and less stringent technical rules (e.g. power limits). On the other hand, in a resource-constrained environment (as is the case of developing countries) legacy equipment is likely to stay around for longer.

⁶⁵ For example, little is known about how spectrum etiquette and enforcement would be implemented. Werbach (2004) defends that common law could be sufficient to address these. Competition law in particular could also help. However, institutional capacity in these areas is often weak in developing countries.